Correlation between Catalytic Activity and Production of Reactive Oxygen Species for Airborne Engineered Palladium Nanoparticles

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Catalyts are widely used in industry, and the catalytic functionality of nanoparticles is a major scientific topic for engineered nanomaterials. However, their influence on human health and biological systems is currently not understood because studies linking the catalytic activity with biological effects are largely unavailable. Therefore, we were investigating correlations between catalytic and biological activity for airborne palladium aerosols as a basis for better understanding of biological effect pathways.

Methods

The catalytic activity of palladium nanoparticles was investigated by the Catalytic Activity Aerosol Monitor (CAAM) which allows the detection of catalytically active nanoparticles (e.g. palladium) with a high sensitivity (Neubauer et al., 2013). As the ability to produce reactive oxygen species (ROS) is believed to be one of the key factors of nanotoxicology (Nel et al., 2006), the generation of ROS was measured by using the DCF method (Le Bel et al., 1992) both in a cell-free environment and with THP-1 cells (human monocytic leukaemia cells).

Experimental

Palladium aerosols produced by spark discharge were thermally conditioned in a tube furnace to generate differently sized palladium primary particles. These aerosols were characterized by an electrical mobility spectrometer for number concentrations and agglomerate size distributions. The mass concentration of the aerosols was determined from filter samples by inductively coupled plasma optical emission spectroscopy (ICP-OES). The geometric diameters of the primary particles were investigated by electron microscopy (TEM).

Detection of the catalytic activity by the CAAM is based on sampling defined volumes of the palladium aerosols onto filters, and then immediately initiating a substance specific chemical reaction on the filter – in this case the hydrogenation of ethene. For this purpose pre-mixed gaseous reaction educts are added to the deposit. The composition of the gaseous reaction products was measured by an IR sensor. Their concentration provides a measure for the catalytic activity of the palladium particles.

For the ROS measurements, the aerosols were transferred into suspension using a phosphate buffered saline. The production of ROS was then determined from these suspensions of differently sized palladium particles via the DCF method. A fluorescence spectrophotometer was used to detect DCF which was formed via the oxidation of non-fluorescent DCFH by ROS. TEM pictures of the suspended palladium were also taken to investigate potential changes in particle size or morphology.

Results

TEM analysis of the palladium aerosols directly after the production gave median primary particle sizes between 3 and 30 nm, depending on preparation. It was also determined that the primary particles did not change their size while the catalytic activity measurements took place, or during their transfer into the liquid.

The measurements with the CAAM showed a pronounced dependence of the activity on the primary palladium particle size, with a sharp maximum at 6 nm. The ROS production also showed a strong size dependence with a maximum in the same size range as the catalytic activity.

Conclusion

The catalytic activity of palladium nanoparticles as determined by a gas-phase reaction correlates strongly with their ability to produce ROS in suspension. This coincidence points to a link between the biological and catalytic activities of palladium nanoparticles. It also demonstrates the usefulness of the CAAM for quasi-real time detection of airborne catalysts.

References

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